apparatus for performing rapid, remote and non-contact inspection of large structures without requiring destruction of portions of the structure.--

B2

--[0002] A number of devices have been developed to perform non-destructive inspection of objects. For example, U.S. Patent Nos. 5,505,090 and 5,616,865 issued to Webster, the contents of each of which are herein incorporated by reference, disclose a device for non-destructively inspecting faults in or beneath the surface of structures, such as debonds or delaminations in composite materials, cracks, broken stringers, and delaminations and the like in semi-monocoque structures. The device includes a spark gap discharge mechanism that is displaced from the object to be inspected. The spark gap discharge mechanism focuses an acoustic pulse onto a small local area of the object for vibrationally exciting the object surface. A laser Doppler camera system, also displaced from the inspection object directs a laser beam onto the excited area and derives, from the reflected light energy, the velocity of the out-of-surface displacement and relaxation frequencies generated by the surface of the excited area which are indicative of whether a fault is located in the area.--

--[0003] A variety of different analysis algorithms may be employed to analyze the reflected light data. U.S. Patent 5,679,899 issued to Webster et al., the contents of which are herein incorporated by reference, discloses a method and apparatus for non-destructive inspection of structures that utilizes a Fast Fourier Transform (FFT) in the analysis process. The FFT is constructed for each sample point and an analysis made to set aside FFT's deviating from a pre-selected standard that represents damaged or other anomalous areas. The remaining FFT's represent an average or statistical FFT spectrum of the undamaged or fault-free area. The average FFT's and the deviating FFT's are then subtracted to provide a clear and unambiguous signal of the fault and other anomalous areas in the structure under inspection.--

--[0004] Each of the above-referenced patents discusses the use of an X-Y scan control system to scan the acoustic pulse generated by the spark gap across a portion of the object to be inspected. The scanning ability, however, is limited to a rather small area of the object under inspection. Accordingly, if large objects or structures are to be inspected, the device must be constantly repositioned and re-calibrated.--

--[0005] In view of the above, it would be beneficial if an automated device and method could be provided that would enable rapid, remote and non-contact inspection of large objects, utilizing non-destructive inspection techniques, that would not require continuous manual repositioning of the inspection equipment.--

B3

--[0006] The present invention provides an automated device and method that enables rapid, remote and non-contact inspection of large objects, utilizing non-destructive inspection techniques, that does not require continuous manual repositioning of the inspection equipment. The inspection system includes a remote controlled robotic vehicle including a sensor package capable of non-destructive inspection of a structure, and a control station that provides control data to the remote controlled robotic vehicle to guide the remote controlled robotic vehicle around the structure. The robotic vehicle is capable of autonomous movement about the structure to be inspected based on data supplied by the control station.--

B4

--[0009] In operation, the control station prepares an inspection plan based on a digitized map of the structure to be inspected and defines a path that the robotic vehicle will travel around the structure based on the inspection plan. The control station performs analysis of data generated by the sensor package to identify anomalies in the structure being inspected.

--[0011] An inspection system in accordance with the present invention is shown in Fig. 1. In the illustrated embodiment, the structure to be inspected is an aircraft, but it will be understood by those skilled in the art that the invention is applicable to any type of object or structure requiring non-destructive inspection.--

B5

Sub C1

--[0012] As shown in Fig. 1, the inspection system includes a remotely located control station 8 and an autonomous computer controlled robotic vehicle 10. The robotic vehicle 10 includes a main chassis 12, an extendable mast 14 attached to the main chassis 12, an articulating arm 16 coupled to the extendable mast 14, and a sensor package 18 attached to the articulating arm 16. The robotic vehicle 10 is controlled to move about a structure to be inspected (the aircraft in the illustrated embodiment) based on commands received from the control station 8 via a wireless communication system. As just one example, a wireless local area network (LAN)

Sub C1 B4

can be provided to facilitate communication between the robotic vehicle 10 and the control station 12. Sensors within the sensor package 18 take non-destructive measurements as the robotic vehicle 10 maneuvers about the structure to be inspected.--

B6

--[0014] The laser positioning head 24 works in conjunction with reflector units 25 (see Fig. 1) that are located around the perimeter of the structure to be inspected. Using the laser positioning head 24 and reflectors 25, positioning measurements are taken to establish a coordinate system that defines a space in which the robotic vehicle 10 will maneuver. Either a point on the structure being inspected or a location within the perimeter defined by the reflectors 25 can be utilized as the origin of the coordinate system. A laser positioning system suitable for use in the illustrated embodiment is available from Lazerway, Inc., a subsidiary company of NDC, Ltd. Alternatively, systems such as those described in U.S. Patents Nos. 5,461,473 and 5,579,102, the contents of which are incorporated herein by reference, may be utilized.--

B7

--[0016] Perspective and cross-sectional views of the articulating arm 16 are respectively illustrated in Figs. 5 and 6. As shown in Fig. 5, the articulating arm 16 includes a mounting assembly 29 to which an outer tube assembly 32 is coupled. An articulating head assembly 34 is coupled to the end of the outer tube assembly 32. The articulating head assembly 34 includes a main body 36 that contains a gearbox coupled to a sensor mounting plate assembly 38 to which the sensor package 18 (not shown) is mounted.--

--[0017] As shown in Fig. 6, the articulating head assembly 34 is also coupled to an inner tube assembly 40 and a drive shaft 42. The inner tube assembly 40 is provided within the outer tube assembly 32. The drive shaft 42 is provided within the inner tube assembly 40. Both the inner tube assembly 40 and the drive shaft 42 are coupled to motors that are mounted on the mounting assembly 29. A drive shaft motor 44 is used to rotate the drive shaft 42, which in is coupled to the sensor mounting plate assembly 38 in a manner to cause rotation of the sensor mounting plate assembly 38 with respect to the main body 36 of the articulating head assembly 34. An inner tube motor 46 is coupled to the inner tube assembly 40 via a drive belt assembly 48 in a manner to cause rotation of the inner tube assembly 40. As the main body 36 of the articulating head assembly 34 is fixed to the opposite end of the inner tube assembly 40, rotation

of the inner tube assembly 40 by the inner tube motor 46 causes the main body 36 of the articulating head assembly 34 to rotate Accordingly, the sensor package 18 that is mounted to the sensor mounting plate assembly 38 is driven two degrees of rotation denoted by arrows A and B.--

B7 cont

B8

--[0019] As shown in Figs. 5 and 6, motor control circuitry 50 is located within a utility box 52 mounted on the mounting assembly 29. Additional rear perspective views illustrating the mounting of the drive shaft motor 44 and inner tube motor 46 are shown in Figs. 7 and 8.--

B9

--[0021] Referring back now to Fig. 1, in the illustrated embodiment, the sensor package 18 includes an acoustic pulse generator 54 that generates an acoustic shock wave (as opposed to a sinusoidal acoustic noise) capable of exciting a vibrational response and resonance in the structure to be inspected, and a Doppler camera system 56 that functions as a vibrometer to measure the vibrational response of the structure being inspected. The acoustic source and the Doppler camera system of the type described in U.S. Patent Nos.: 5,505,090; 5,616,865; and 5,679,899 may be utilized as the acoustic pulse generator 54 and the Doppler camera system 56. It will be understood, however, that any type of non-destructive sensor may be employed in the sensor package 18 depending on the specific application.--

B10

--[0023] As shown in the exploded view illustrated in Fig. 12, the main body 60 preferably includes a two dimensional parabolic reflector 68, located such that the focal point is at the location of the spark gap, which shapes and reflects the shock wave generated at the spark gap to produce a more planar wave front at the structure to be inspected, thereby enabling more simultaneous excitation over the excited area than previous acoustic sources of the type described above. The flame arrestor structure 62 is preferably made of a plurality of parallel plates, for example stainless steels, that are spaced apart and act as "Davy" plates to prevent propagation of a flame through the flame arrestor structure 62 that might ignite flammable materials in the environment around the structure to be inspected.--

B11

--[0027] The setup control functions include a variety of actions that are taken to prepare for the maneuvering of the robotic vehicle 10 around the structure to be inspected. For

example, in the case of aircraft inspection, a digitized map of the aircraft model to be inspected is retrieved from a database. Alternatively, if one is available, a digitized map of the specific aircraft is retrieved from a database. An inspection plan is then developed based on the digitized map of the aircraft model or specific aircraft. The inspection plan, for example, identifies a number of inspection points to be investigated on that particular model of aircraft. The number of inspection points may vary based on the age and type of aircraft involved. Once the inspection plan is developed, autonomous ground vehicle (AGV) path planning is performed. The AGV path planning determines the path which the robotic vehicle 10 will take as it is maneuvered around the aircraft to reach each of the identified inspection points. Data related to the AGV is downloaded to the robotic vehicle 10, allowing the vehicle to operate autonomously once the inspection routine begins.--

B11 Cont

--[0029] The interpretations functions are utilized to perform interpretation and analysis of data to determine if faults are present within the structure being inspected. The interpretation functions include data analysis, data catalogue generation, anomaly identification, anomaly classification and report generation. As stated above, a variety of algorithms may be utilized to perform the data analysis, as well as the anomaly detection and classification. In the case of the use of acoustic vibration signals (surface velocity vs. time) discussed above, time and frequency domain based signal processing algorithms are used to identify, classify, size and locate anomalies without operator intervention.--

B12

Abstract

--An automated inspection system and method enables rapid, remote and non-contact inspection of large objects, utilizing non-destructive inspection techniques, that does not require continuous manual repositioning of the inspection equipment. The inspection system includes a remote controlled robotic vehicle including a sensor package capable of non-destructive inspection of a structure and a mechanism for locating the sensor package at a plurality of inspection sights on the structure; a positioning system for determining the location of the robotic vehicle with respect to the structure to be inspected; a control system for controlling the movement of the robotic vehicle around the structure to be inspected; and an analysis systems for analyzing data generated by the sensor platform.--

B13